Atmos. Chem. Phys. Discuss., 3, S2431–S2437, 2003
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Atmospheric Chemistry and Physics Discussions

ACPD

3, S2431–S2437, 2003

Interactive Comment

# *Interactive comment on* "Technical note: an interannual inversion method for continuous $CO_2$ data" *by* R. M. Law

**R. M. Law**

Received and published: 16 January 2004

Reply to Paul Palmer review

This review has been useful in prompting further thought about the methodology presented here, particularly its mathematical basis. I have detailed below responses to the issues raised.

GENERAL COMMENTS

The reviewer asks about the ability of 4 hr data to improve sources estimates particularly the `missing sink'.

The potential of high temporal frequency data to improve source estimates was shown and discussed in two previous papers, Law et al. (2002) [L02] and Law et al. (2003) [L03]. Given that the focus of this paper is on the technical aspects of performing interannual inversions with continuous data, I do not feel that there is a need to discuss the potential of the data further. The paper does show that there are limitations to the current inversion method that result in biased source estimates and that the long-term mean biases are sometimes larger using 4 hour data than monthly data. This could compromise estimates of the so-called `missing sink' since I equate this to a long-term mean flux. However I think that there is as much, if not more, interest in using inversions to estimate interannual variations in flux since these may be used to better understand CO2 exchange processes. Trends in flux are also of interest. Both require the type of interannual inversion presented here and this work shows that 4 hourly data gives better interannual estimates than monthly data.

SPECIFIC COMMENTS

1) independence of data and autocorrelation

The inversion assumes that the data residuals (the difference between the original data and the data fit) are independent. This is not the case with the four-hourly data used here. In fact, depending on the site, we find autocorrelations greater than 0.2 for up to 1-4 days. We should note that these autocorrelations are larger than we would expect if we were inverting real data which will be noisier than the model-generated timeseries used here. It is difficult to assess the impact of the autocorrelation on the inversion; the uncertainty on the source estimates would increase but it is not clear how source biases would change. It is tempting to average the data over a few days before inverting but L03 showed that biases tend to increase with averaging period. A solution is to include temporal correlations in the inversion and this is a good direction for future work.

2) representation error

Assuming representation error is about the ability of the transport model to represent the observations at a site, then the only way to account for this is in the data uncertainty term. I have chosen data uncertainties that are large relative to measurement precision to allow for representation error. The use of spatially variable (rather than constant) data uncertainties also allows for the expectation that representation errors will be larger for regions where the fluxes are larger and more variable. The data uncertainties used for the four hourly data are twice those used for the monthly data which allows for some scaling of representation error with time. The data residuals from the inversion (predicted data fit minus original data) are on average substantially smaller than the chosen data uncertainties for both the four hour and monthly cases. This indicates that any representation error has been adequately accommodated by the chosen data uncertainties. We should note that representation error will be larger for real data than for the model-generated data used here and so the magnitude of data uncertainties may need to be modified in future work. I will add a note in section 2.2 that the data uncertainty incorporates representation error.

3) how well can regions be retrieved / independence of retrieved state vector

The independence of the retrieved estimates tells us how well fluxes from different regions can be separated while the posterior uncertainty is a measure of how well the sources can be retrieved for any individual region. I chose not to show the uncertainties here as earlier work (L02,L03) had shown that it was possible to get very small uncertainties with four hourly data compared to monthly data but that the source estimates could still show significant bias. In essence the uncertainty indicates the potential of the data while the bias tells us about the limitations of our current inversion method, which was what we wanted to determine here. Having said that, the posterior uncertainties are much smaller using the four hourly data, for example the prior uncertainty on the annual mean flux is reduced by over 50% for more than half the regions using four hourly data but for only 3 regions when using monthly mean data.

4) final figure

The final figure (6) was originally submitted as supplementary material. As part of the paper it fits more logically as Figure 1 and I will make this change. I will refer to Table

1 in the figure caption.

5) appropriateness of ignoring covariance, are the covariances significant?

The comparison described in section 2.1 between the sequential method and a five-year inversion gives some information about the significance of the covariance because the five-year inversion will treat the covariances correctly. Since the results are reasonably similar it suggests that the covariances are small and that we are not seriously compromising our estimates by ignoring the covariance. I will add a sentence to the end of section 2.1 to note this.

6) page 5982: 'unrealistic' 1981 sources

The 1981 sources are described as unreliable rather than unrealistic. It is possible that the estimates are quite reasonable especially for the later months of 1981. The problem with the early months is that concentration measurements through this period will be influenced by sources that occur before 1981 while the method employed here assumes no sources before 1981. The problems are likely to be largest for regions away from a site since these regions are more reliant on signals that have taken some time to reach an observing location.

7) e-folding time of monthly responses

It is not clear to me exactly what the reviewer is asking. If the question is about the rate at which the concentration signal decays to a background level at any given site then this is already given in section 2.3. For the one test site that I examined, I found that an e-folding time of approximately 90 days provided a reasonable fit to the concentration timeseries beyond 3 months.

8) addition of noise to modelled sources

If noise were to be added, I would expect to add it to the concentrations that are modelled from the sources rather than to the sources themselves. In either case, noise was not added. In this study, I thought it best to use as clean a test as possible to evaluate



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the sequential inversion method. L03 examined the impact of adding noise to the concentration data with a cyclo-stationary inversion set-up and data at different temporal frequency. We found that with more frequent data, the impact on the inversion was smaller for a given magnitude of noise.

9) 'shape' of interannual variability

I will re-write this sentence to make this clearer.

10) r or r2

I use the correlation, r.

11) sensitivity to prior uncertainty gives information about data constraint?

A lack of sensitivity to the prior uncertainty is not always an indicator that the source estimates are largely constrained by the concentration data. For example, let us consider each region in our standard and low prior uncertainty experiments. We use the change in bias in 1982-1997 mean flux as our measure of sensitivity to the prior uncertainty. As a measure of the data constraint we use the ratio of posterior to prior source uncertainty from the standard inversion. We find that we can get both large and small sensitivities to the prior uncertainty for regions with a weak data constraint but we only find small sensitivities to the prior uncertainty when a region is strongly constrained by the data, i.e. a strong data constraint implies a low sensitivity but the opposite is not always true.

12) relative bias more useful?

Plotting relative bias tends to give greater emphasis to biases that occur for regions where the correct source is small. I think that a bias of a given magnitude is equally significant whether it is a bias on a small source or on a large source. Hence I am more comfortable plotting the absolute bias rather than the relative bias.

13) clarity of figure 5, show all cases as difference from truth?



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I have tried plotting all cases versus the truth as suggested but this does not make the figure clearer. The impact of shortening the response function from 12 to 3, 6, and 9 months, which is the intended focus of the figure, tends to be lost in the relatively large differences between the 12 month response and the truth. I will try to improve the clarity of the figure caption.

TECHNICAL COMMENTS

1) Remove 'two years' in step 2 of method description

I will do this.

2) doubled source uncertainties

Is there some confusion here? The text on p5979 refers to the source uncertainties while the text on p5981 refers to data uncertainties. The source uncertainties used are the same for the four-hourly and monthly inversions while the data uncertainties in the four-hour case are double those in the monthly case. There is a factor of two mentioned in relation to the source uncertainties but this is only to indicate how the Transcom3-level3 uncertainties (on which our case is based) were derived from the Transcom3-annual mean uncertainties. I will re-write the paragraph on the data uncertainties (also requested in 2nd review), hopefully reducing the potential for confusion.

3) page 5984 mention land/ocean allocation will be discussed later

I will do this.

References

Law R.M., P.J. Rayner, L.P. Steele and I.G. Enting, Using high temporal frequency data for $CO_2$ inversions, Global Biogeochem. Cycles, 16, 1053, doi:10.1029/2001GB001593, 2002.

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Interactive comment on Atmos. Chem. Phys. Discuss., 3, 5977, 2003.



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